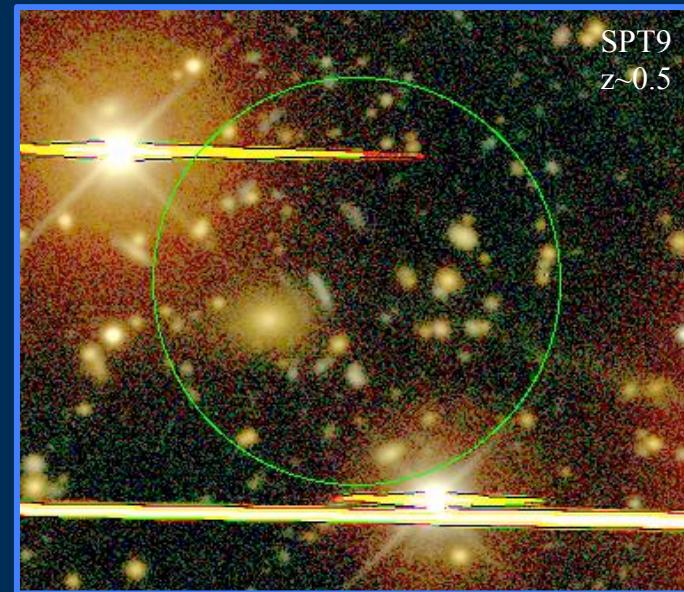


“Future Multiwavelength Surveys of Galaxy Clusters”

Joe Mohr

Department of Astronomy, Department of Physics
National Center for Supercomputing Applications
University of Illinois



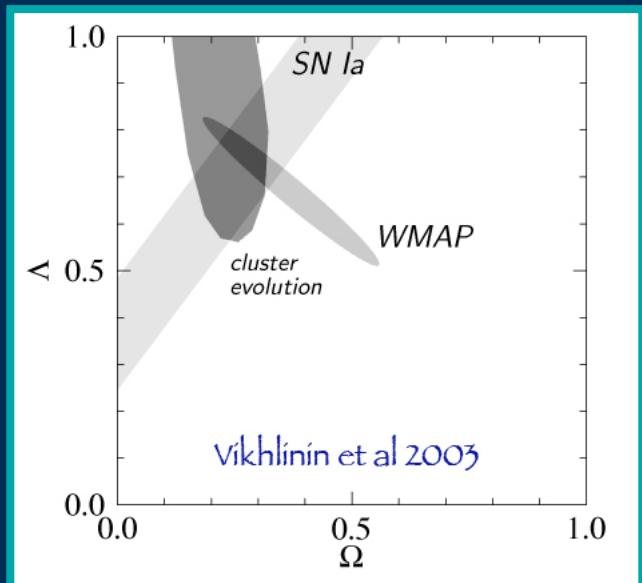
Outline

- Cluster surveys
- South Pole Telescope
- Ongoing Multiwavelength Program
- Dark Energy Survey (+ VISTA, +VST?)
- e-ROSITA

Cluster Surveys Are Underway

- ROSAT Archive
 - REFLEX/NORAS (Böhringer et al)
 - 160d/400d survey (Vikhlinin et al)
 - MACS survey (Ebeling et al)
- Optical surveys
 - RCS (Gladders et al)
 - SDSS (Rozo et al)
- Chandra and XMM observatories
 - Serendipitous surveys
- SZE surveys
 - SPT (Carlstrom et al)
 - ACT (Page et al)

Figure courtesy Alexey Vikhlinin



ROSAT 160d survey yields
 2σ detection of Λ
(50 local clusters + 18 $z \sim 0.55$ clusters)

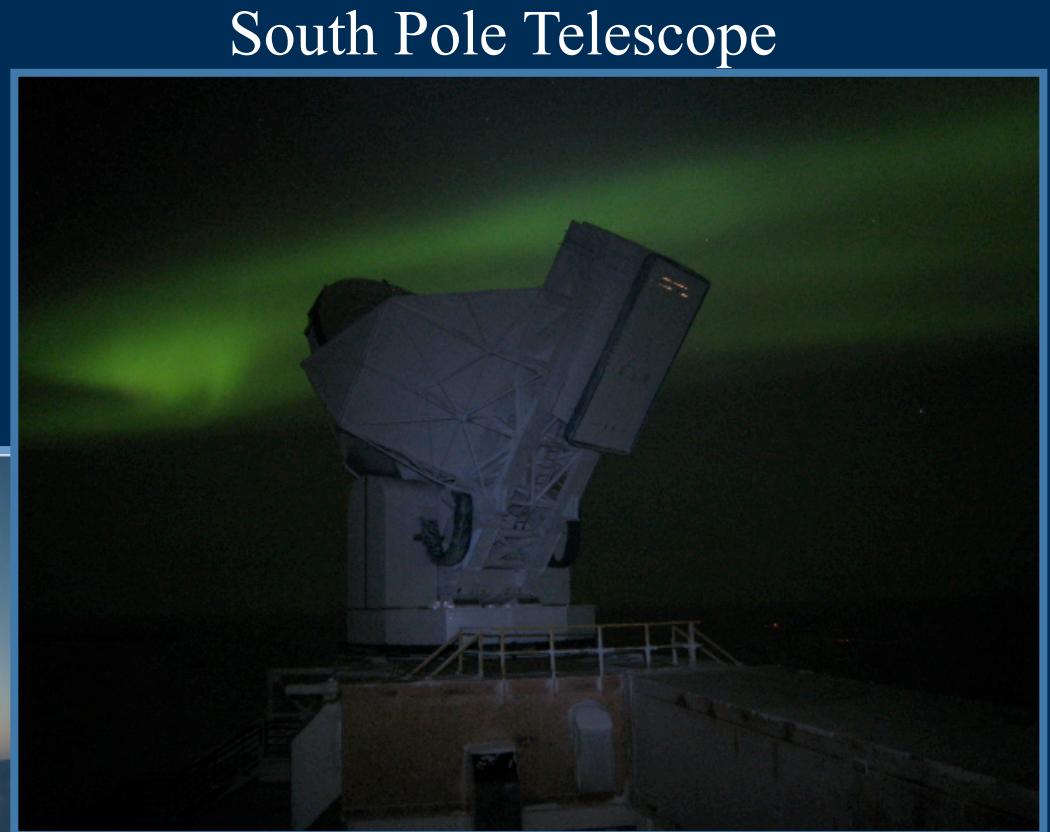
ROSAT 400d survey yields
w constraints
(37 $z \sim 0.55$ clusters)

South Pole Telescope (SPT) Operating at the Pole

- Feb 16, 2007 first light for 10m SPT
- Bolometer arrays at 90, 150, 220GHz
- Deep, arcminute resolution maps now available for the first time
- Science survey began in May, 2007
 - Two 100 deg² deep fields completed
 - Large number of pointed cluster obs
 - First SZE selected clusters found (i.e. Staniszewski et al 2008)



November 21, 2008



Picture by Steve Padin on June 10, 2007

<http://spt.uchicago.edu>

Great Surveys Workshop - Mohr

SPT Collaboration

John Carlstrom, PI



William Holzapfel
Adrian Lee
Martin White
Sherry Cho
Huan Tran
Martin Lueker
Jared Mehl
Tom Plagge
Christian Reichart
Dan Schwan
Erik Shirokoff
Oliver Zahn



Helmuth Spieler



John Ruhl
Tom Montroy
Zak Staniszewski



Harvard-Smithsonian
Center for Astrophysics

Antony Stark
Chris Stubbs



Joe Mohr
Choong Ngeow
Jeeseon Song
Alfredo Zenteno



THE UNIVERSITY OF
CHICAGO

John Carlstrom
Steve Padin
Stephan Meyer
Clem Pryke
Wayne Hu
Andrey Kravtsov
Brad Benson
Tom Crawford
Jeff McMahon
Clarence Chang
Kathryn Minkaitis
Nils Halverson

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University of Colorado at Boulder

McGill

Matt Dobbs
Gil Holder
Trevor Lanting

CARDIFF
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CAERDYDD

Peter Ade

KICP

Kavli Institute
for Cosmological Physics
AT THE UNIVERSITY OF CHICAGO

Joaquin Vieira
Abbie Crites
Ryan Keisler
Lindsey Bleem
Jonathan Stricker

JPL

Erik Leitch

UCDAVIS

UNIVERSITY OF CALIFORNIA

Lloyd Knox
Jason Dick

Galaxy Cluster Redshift Distribution is Sensitive to the Dark Energy Equation of State

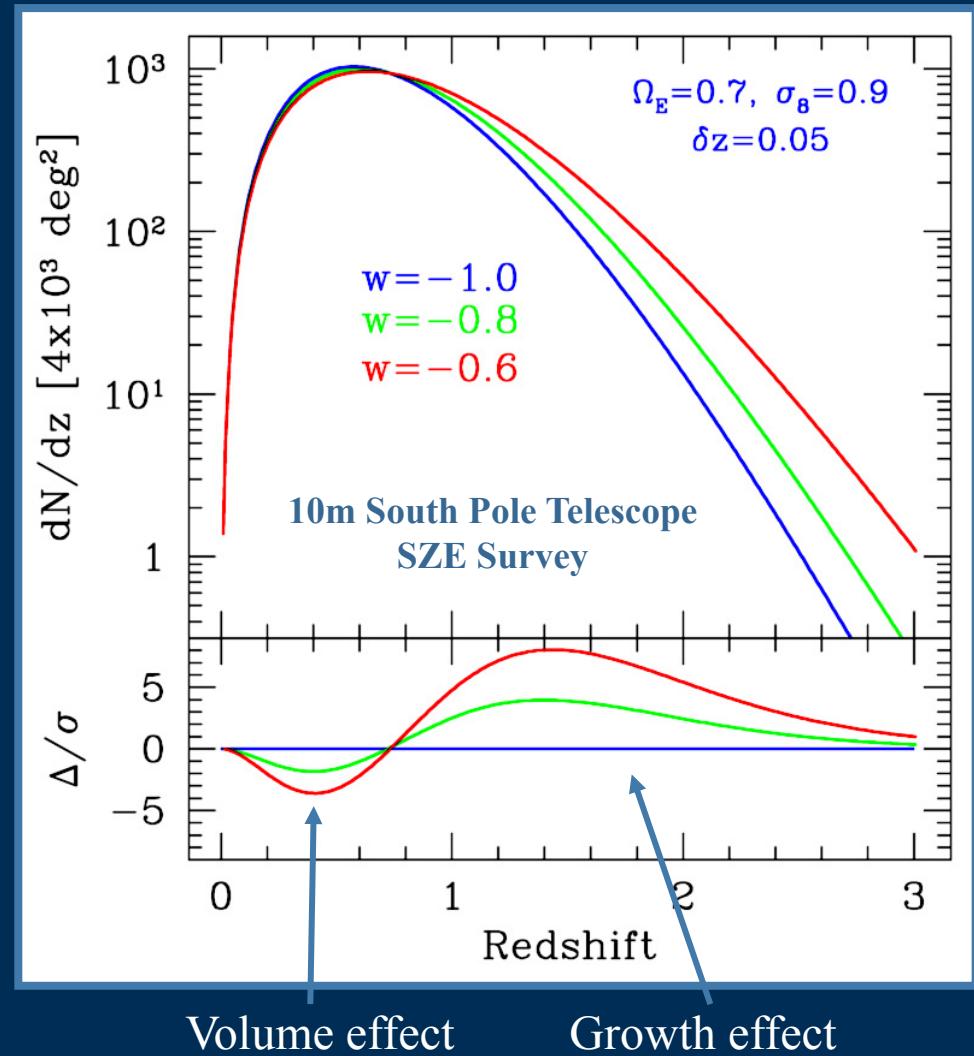
- Cluster surveys provide
 - Redshift distribution
 - Luminosity (mass) function
 - Cluster power spectrum (i.e. BAO)
 - Direct mass calibration
- Each has different cosmological dependence-- very rich dataset

$$\frac{dN(z)}{dz d\Omega} = \frac{dV}{dz d\Omega} n(z)$$

w dependency:

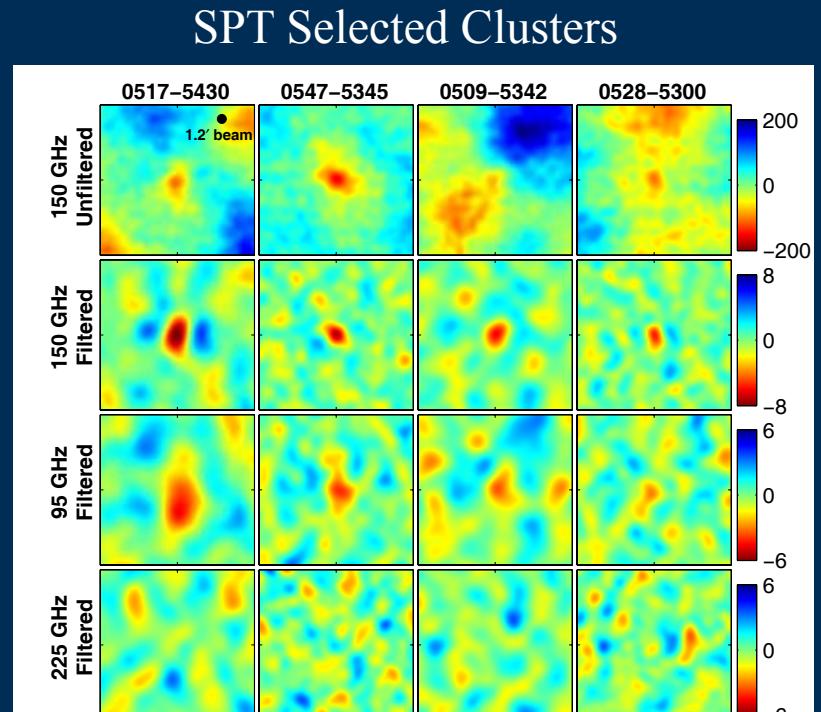
Raising w at fixed Ω_E :

- Decreases volume surveyed
- Decreases growth rate of density perturbations



First SZE Selected Clusters

- Feasibility demonstrated this year
- SZE survey
 - SZE flux closely coupled to cluster mass, independent of redshift
 - Unique spectral signature- should be essentially no contamination in multifrequency surveys like those from SPT and ACT; less need for optical counterpart to confirm than in X-ray
 - Radio AGN can bias flux, even overwhelm cluster- affects completeness
 - Better at higher frequencies (i.e. 150GHz instead of 15GHz and 30GHz)
 - Arcminute resolution insufficient for cluster-AGN separation
 - Completeness untested

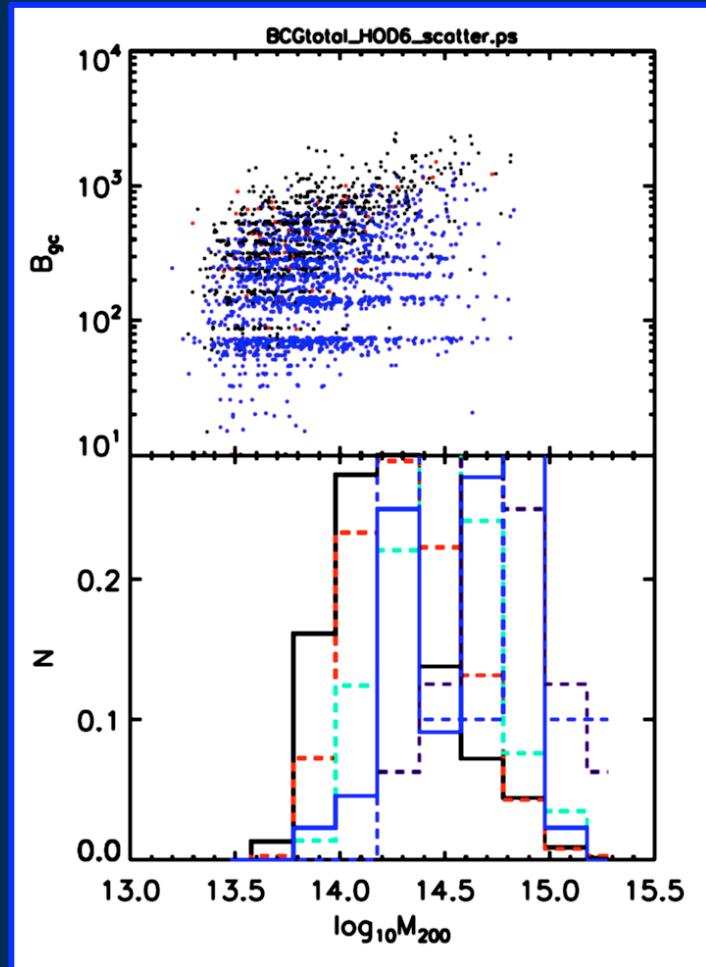


Staniszewski et al 2008

Cluster Surveys are Naturally Multiwavelength

- Cosmology relies on cluster selection model and mass information
- Best mass indicators come from X-ray and (we hope) SZE
- Good mass indicators enable clean selection
(i.e. flux cuts \sim mass cuts as $f(z)$)
- Optical/NIR/IR absolutely necessary:
Redshifts
Weak lensing masses for mass calibration
To date no galaxy based mass indicator has emerged that tracks cluster halo mass as well as intracluster medium mass indicators

BGC versus Mass in Simulated Catalog

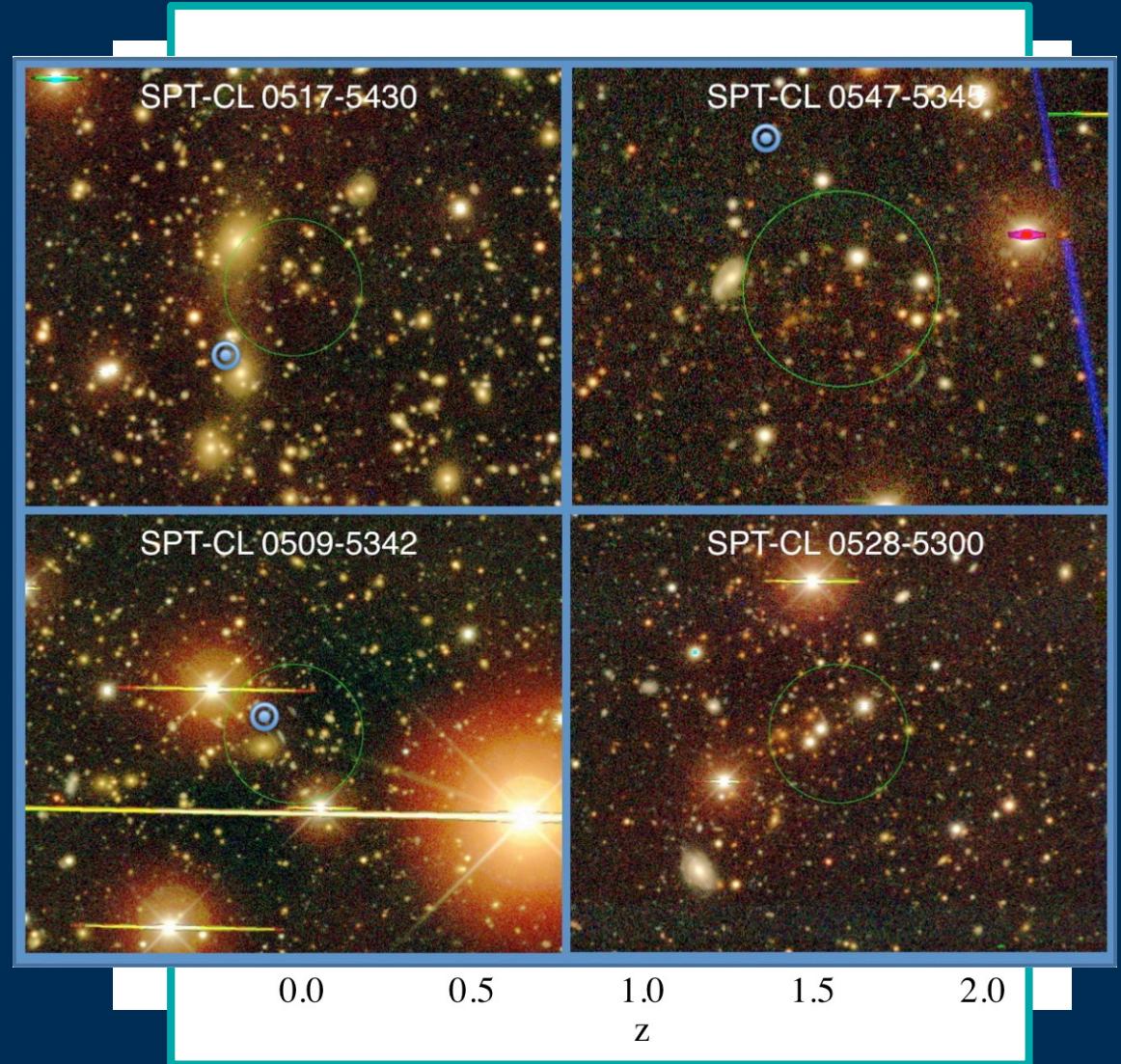


Song et al 2008
consistent with Gladders et al '07



SPT Discovery Clusters

- *griz* images by BCS
 - Photo-z's
 - CMR Redshifts
 - LF's, Halo Occupation
- Gemini spectroscopy proposed
 - Giant arc redshifts
 - Velocity Dispersions
- Chandra obs scheduled
 - X-ray mass estimates
 - Substructure





The Blanco Cosmology Survey

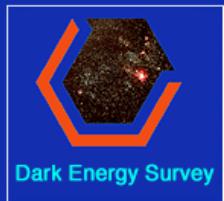
see <http://cosmology.uiuc.edu/BCS>

- Science Goals:
 - Enable early science with SPT
 - Establish multiwavelength cluster finding testbed to enable precise cluster survey cosmology
 - Execute “optical-only” science in intermediate solid angle field imaged 10x deeper than SDSS
- Two 50 deg² BCS Fields to allow efficient observing
 - Target depths (10σ in 2.3 arcsec aperture)
 - L* to z=1 for cluster galaxies
 - g,r,i,z=24,23.9,23.6,22.3
- Seven photo-z calibration fields with large samples of spectroscopic redshifts
 - CDFS, DEEP2, CFRS, CNOC2, SDSS Southern Stripe

Blanco 4m on Cerro Tololo, Chile



Image credit: Roger Smith/NOAO/AURA/NSF

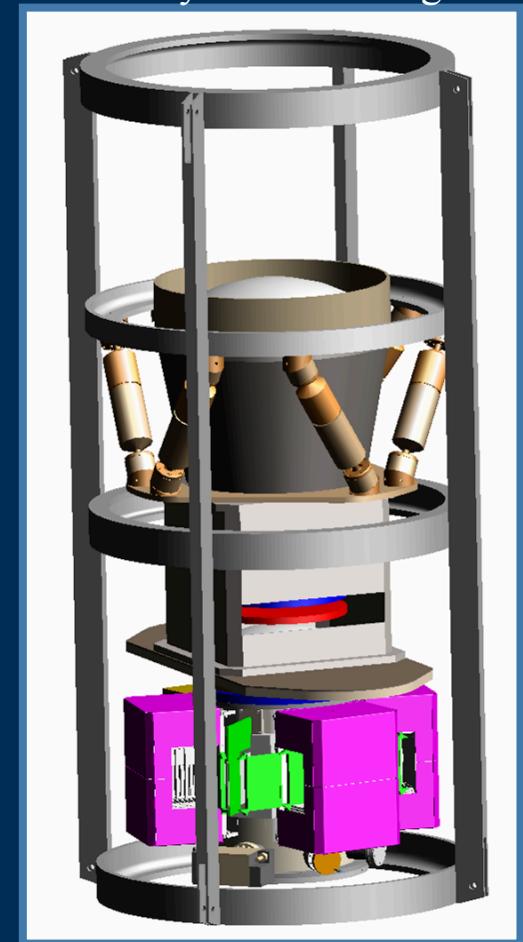


The Dark Energy Survey

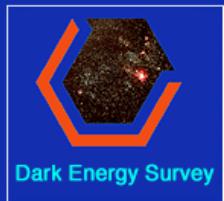
see <http://www.darkenergysurvey.org>

- DES designed to provide full optical followup of the SPT survey (photo-z's, WL cluster masses, SZE+optical selection)
- Actually much more! A study of DE using four techniques
 - Galaxy cluster surveys (SPT followup)
 - Galaxy angular power spectrum
 - Weak lensing/cosmic shear
 - SN Ia distances
- Two linked, multiband optical surveys
 - 5000 deg² grizY (photo-z's to 0.5 L* out to z=1.35)
 - Repeated observations of 9 deg² (~2000 SNe Ia)
 - Uses 525 guaranteed nights on CTIO 4m (2011-2016)
- Status- fully approved, camera at CTIO Dec '10, survey Oct '11
 - DECam construction funded at Fermilab
(DOE PI Flaugher)
 - DM development funded at Illinois/NCSA
(NSF PI Mohr)
 - Additional funding from UK, Spain, Brazil, Universities

Courtesy Brenna Flaugher



DECam + 2 degree FOV Corrector in Prime Focus Cage

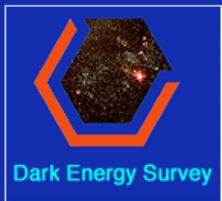


DES Collaboration

John Peoples, Director

12 participating institutions and >100 participants

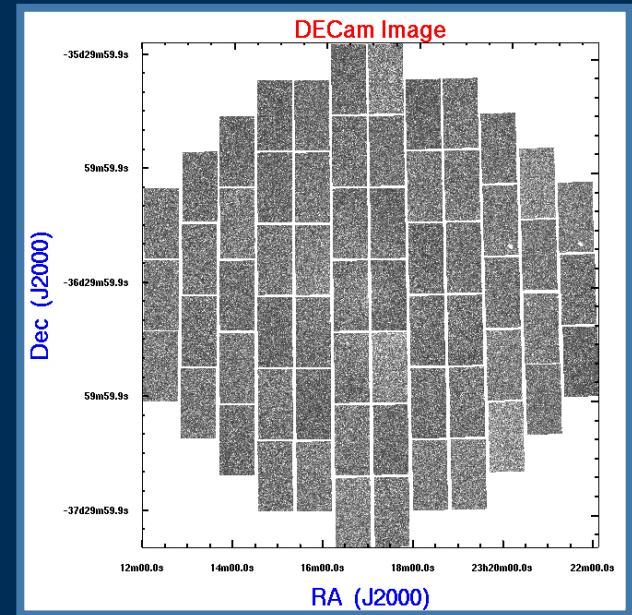
- **Fermilab**
- **University of Illinois**
- **University of Chicago**
- **Lawrence Berkeley National Laboratory**
- **University of Michigan**
- **NOAO/CTIO**
- **Spain-DES Collaboration:**
Institut d'Estudis Espacials de Catalunya (IEEC/ICE), Institut de Fisica d'Altes Energies (IFAE), CIEMAT-Madrid:
- **United Kingdom-DES Collaboration:**
University College London, University of Cambridge, University of Edinburgh, University of Portsmouth, University of Sussex
- **The University of Pennsylvania**
- **Brazil-DES Consortium**
- **The Ohio State University**
- **Argonne National Laboratory**



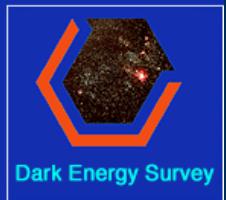
DESDM Project Overview

<http://desweb.cosmology.uiuc.edu/wiki>

- DESDM Project has two deliverables:
 1. The DESDM System to support DES science
 2. The Community Pipeline for processing DECam data for non-DES observers
- The DESDM system will:
 - Be deployed at NCSA to process DES data into science ready data products
 - Archive DES image and catalog data over the long term
 - ~2.5PB total, including 100TB database
 - Distribute data to Collaboration
 - Enable community access to public DES data
 - Raw and processed data 1 yr after acquisition
 - Coadd/catalogs at midpoint and end of survey
- The Community Pipeline will be:
 - Integrated into the NOAO E2E system
 - Operated by NOAO for the reduction of DECam data taken by other observers



Single DECam exposure (500Mpix) consists of 62 individual CCD images



DESDM Project Team

- **U Illinois Team**

- Darren Adams
- Cristina Beldica
- Dora Cai
- Tony Darnell
- Greg Daues
- Shantanu Desai
- Michelle Gower
- Joe Mohr
- Choong Ngeow

- **Institut d'Astrophysique**

- Emmanuel Bertin

- **Lensing Pipeline**

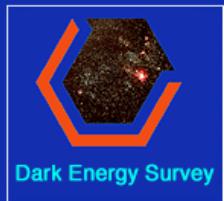
- Mike Jarvis (U Penn)
- Erin Sheldon (Brookhaven)

- **Fermilab Team**

- Eric Neilsen
- Douglas Tucker
- Huan Lin

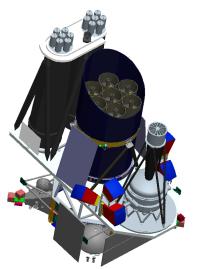
- **Collaborating Groups**

- DECam Sim team (Lin, Stoughton, Kuropatkin)
- NOAO Data Products (Smith, Stobie et al)
- BCS/SPT/SCS science (Zenteno, Song, Brodwin, Gonzalez, Barkhouse, Faßbender, ...)
- SNe Science Working Group
- Brazilian team



Challenges/Lessons Learned

- Timescale
 - Planning began in 2003, funding/approval by DOE and NSF in 2007
 - Survey: planned to begin in 2008, scheduled to begin in 2011
- Existence
 - Fitting in the cracks between large projects:
DES: \$30M camera, \$15M DM (\$7.5 devel), \$5M Blanco ops
Competition complicates collaborative development
- Technical
 - Data volume: drives us to high performance computing environment
 - Ensuring the product meets the needs of the scientists
 - Scientific leadership *and* professional project management
 - Testing early and often- data challenges- using simulated and real data
 - Involving science teams in analysis/access of these early data products
 - Implementing key analysis pipelines within DM environment



eROSITA, All Sky X-ray Survey

*extended ROentgen Survey with an Imaging Telescope Array
Main Instrument on Spektr-RG (2012-2015)*

PI: Peter Predehl

Co-Is: Hans Böhringer, Ulrich Briel, Hermann Brunner, Evgeniy Churazov, Michael Freyberg, Peter Friedrich, **Günther Hasinger**, Eckhard Kendziorra, Dieter Lutz, Norbert Meidinger, Mikhail Pavlinsky, Andrea Santangelo, Jürgen Schmitt, Axel Schwone, Matthias Steinmetz, Lothar Strüder, Rashid Sunyaev, Jörn Wilms

System Engineer: Josef Eder

Product Assurance: H. Bräuninger, M. Hengmuth

Electronics Engineering: W. Bornemann, O. Hälker, S. Hermann, W. Kink, S. Müller, Th. Schanz, O. Hans

Mechanical Engineering: H. Huber, Chr. Rohé, L. Tiedemann, R. Schreib, B. Mican, K. Lehmann, H. Eibl, F. Huber, R. Sandmair

Mirror System, PANTER: P. Friedrich, W. Burkert, M. Freyberg, B. Budau, V. Burwitz

Cooling, Thermal Engineering: M. Fürmetz

CCD-Camera: N. Meidinger, Robert Hartmann, E. Pfeffermann, G. Schächner, J. Elbs, S. Ebermayer

Attitude: A. Schwone

Calibration, Analysis: G. Hartner, K. Misaki, U. Briel, K. Dennerl, R. Andritschke, Chr. Tenzer

Laboratory, Tests: M. Vongehr, L. Hirschinger, K. Dittrich, F. Schrey

Ground Software, Simulation: H. Brunner, N. Cappelluti, G. Lamer, M. Mühlegger, J. Wilms, I. Kreykenbohm, Chr. Schmid

Mission Planning: J. Schmitt, J. Robrade

Institutes:

Max-Planck-Institut für extraterrestrische Physik, Garching/D

Space Research Institute IKI, Moscow/Ru

Univ. Tübingen/D

Univ. Hamburg/D

Univ. Erlangen-Nürnberg/D

Astrophysikalisches Institut Potsdam/D

Max-Planck-Institut für Astrophysik/D

Industry:

Kayser-Threde/D

Media Lario/I

Carl Zeiss/D

Invent/D

pnSensor/D

...

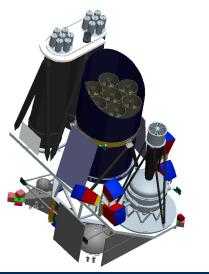
Mirror System

Mirror Modules

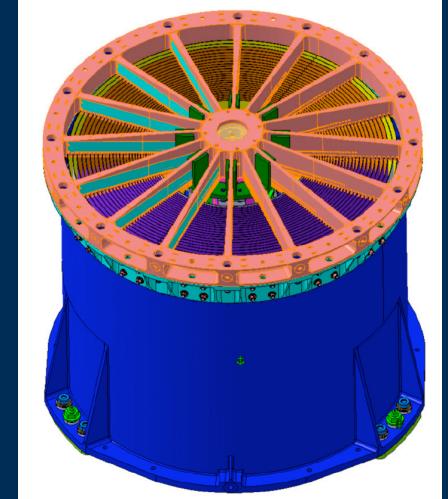
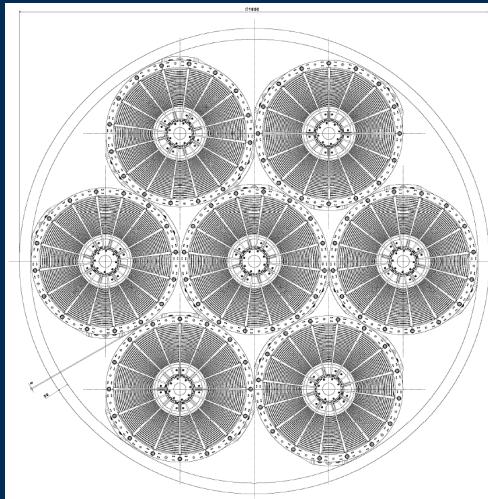
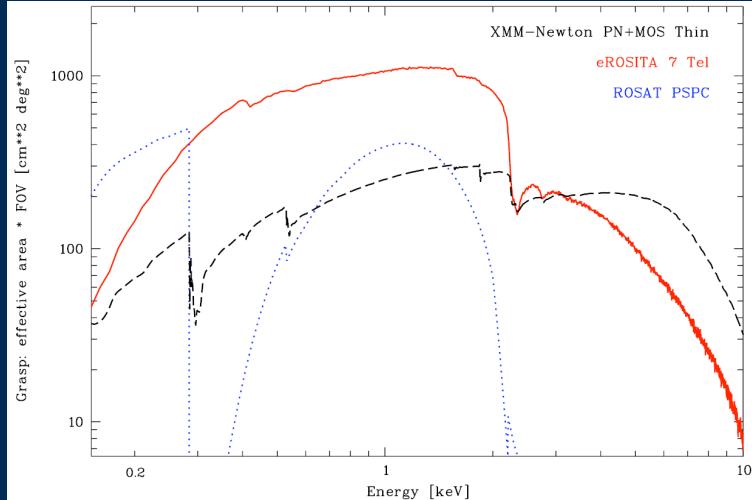
Mirror Mandrels

Telescope Structure

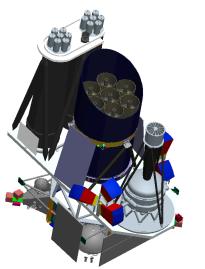
CCDs



Mirror System



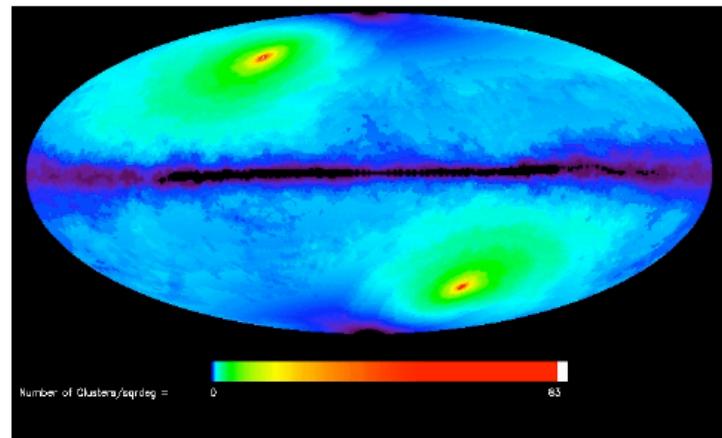
- 7 Mirror Modules, 54 shells each, 360mm Ø, f=1.600mm
- 350 square cm each (totals 2 x XMM-Newton)
- 1 degree diameter FOV
- Characteristic flux limit is $\sim 10^{-14}$ erg/s/cm²
(~60X deeper than ROSAT)



Cluster Detection

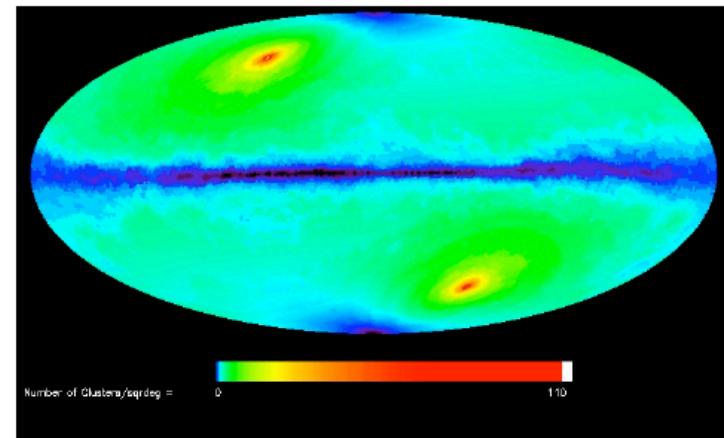
M. Mühlegger

Calculated number of eROSITA photons for clusters in the Hubble Volume simulation
(depending on redshift, galactic hydrogen, exposure map)



Countlimit = 100 cts

79 912 galaxy clusters found,
69 809 with $|b| > 20$ deg



Countslimit = 50 cts

179 484 galaxy clusters found,
155182 with $|b| > 20$ deg

-> what's a correct assumption for the countlimit?

Overview

SPT cluster survey underway

- Multiwavelength cluster science underway in SPT region:
XMM, Spitzer, Chandra, optical/NIR imaging and optical spectroscopy
- Stay tuned...

Dark Energy Survey is funded

- Photometric depths to ~25 in grizY (5σ pt src) over 5000 deg^2
~2hr of 4m exposure at every location in this region (with modern red sensitive CCDs)
- Survey starts Oct '11, continues for 5 yrs (525 nights)
- Full region images between 8 and 10 times at end of first season
- Coordinated with VISTA (JHK) and perhaps VST (u)

All Sky X-ray survey e-ROSITA is funded

- German instrument on Russian satellite (Spektr-RG)
- Targeting 2012 launch and 4 year mission